NUCLEAR POWER PLANT MALFUNCTIONS: POTENTIAL TYPES OF EXPOSURE AND SEVERITY*

HAROLD W. LEWIS, Ph.D

Department of Physics
University of California
Santa Barbara, California

THERE are two important things to recognize about malfunctions in nuclear power plants. One is that they will happen. There is simply no question that things made by and operated by people, no matter how well made, will malfunction from time to time. Something will go wrong. We have had over the course of the history of the nuclear power industry many accidents—many of them, in my view, with greater implications for the safety of the technology than the Three Mile Island accident, but certainly the Three Mile Island accident has gotten the lion's share of the publicity. But the variety of accidents that we have had simply illustrates the general fact that these are very complicated plants. Some of the pipes that look fairly small in the slides that Dr. Hendrie showed are three feet in diameter. And pipes three feet in diameter, with water rushing through them with the speed of a freight train, are very impressive gadgets. Accidents will happen. The second important lesson is that not every accident will be the worst possible accident. A terrible mistake that people make, and I lay a lot of blame on the antinuclear folks for this, is always to think in terms of the worst thing that can happen. That can deprive one of the capability to deal with the things that really will happen.

If a fire department were to practice only on events like the *Towering Inferno* they would be ill equipped to put out wastebasket fires. But they spend more of their time putting out wastebasket fires than they do dealing with terrible fires in skyscrapers.

The tendency, and it is perhaps a natural human tendency, is always to think of the worst thing that can happen and to base planning and education on that can be quite wrong. It can mislead one in dealing with the affairs of the real world.

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There are those of us who feel that, in a certain sense, this is a problem not confined to nuclear power; it is also a problem of national defense. If one spends all one's time dealing with cataclysm and with the worst possible nuclear war, one can forget what the problem of preserving the peace is all about and can be badly misled.

There are people who spend a great deal of time pushing the attention of the community toward the worst thing that can possibly happen. That is bad for several reasons. One reason is that it deprives us of the opportunity to deal with real things. The other is that it actually makes the less severe but more likely things more likely because we have not prepared for them.

I cite a very specific example. Those of us who are in the nuclear safety game have been bemoaning for years that a major fraction of the research program of the Nuclear Regulatory Commission has been devoted to the problem of very large breaks in very large pipes, the so-called large loss of coolant accident in the 36-inch pipes that I mentioned a moment ago. The fact is that none of these have ever broken, but it is true that if one of them breaks, it would be a very severe accident. For many years the Nuclear Regulatory Commission has devoted a major fraction of its attention (although it is beginning to diminish a little bit) to breaks in those pipes, and that has, in my view, contributed to the neglect of the things that led to, for example, the Three Mile Island accident.

So I adjure against thinking in terms of the worst catastrophe. There is what is known as a risk probability curve, which is a way of saying that things that are less severe generally happen more often than things that are very severe. This is not to say that the very severe ones will not happen, but only that they are really less likely. One must be prepared for them, but not exclusively. That is my speech on large-scale events.

Now, what kind of accidents can there be, and what ought we to know about them? The main issue associated with a nuclear power plant that distinguishes it from any other major industrial gadget is that there are contained in this very large containment large quantities of radioactivity. For those who are familiar with the radiation units, a large nuclear power plant has something like 10 billion curies of radioactivity stored after it has been operating for a reasonable length of time. That is a lot of curies. The objective in reactor safety is, by one means or another, to keep that inventory of radioactive materials out of the public domain, and keep it where it belongs in spite of malfunction. I shall not dwell on safety philosophy; Dr. Hendrie has referred to it. It is defense in depth, redundancy, and so forth. The thing that can happen in the event of a nuclear accident, if the worst comes to the worst and the containment is breached in some way, is release of radioactivity into the environment.

One very important fact to know is that a nuclear reactor simply cannot blow up with a mushroom cloud. Many of the cartoons one sees in the paper show a nuclear power plant with a mushroom cloud on top of it. That is scientifically impossible. There is no way in which a light water plant of the sort we are talking about can have what is called a fast critical reaction leading to a detonation. It absolutely cannot happen.

Releases of radioactivity from a nuclear plant occur over a longer period of time. That is the second point about a nuclear accident. Nuclear accidents do take time. There is essentially no likelihood that one can quite suddenly have a major release of radioactivity into the environment. Indeed, much of the problem of dealing with a plant malfunction will be trying to figure out whether or not a radiation emergency is really going to happen. In reading the history of Three Mile Island, which is fully documented, one finds that a great deal of the concern of the members of the Nuclear Regulatory Commission during the early stages was: How bad is it going to get? And the fact is that no one really knew that during the course of hours at the least, and days at the most. Dr. Hendrie, who just spoke, knows that all too well. As chairman of the Nuclear Regulatory Commission at the time of the accident, he allowed his remarks to be tape recorded, which I always regarded as one of the bravest things anybody ever did, so that everything that he said and did during those hectic days is available for Monday morning quarterbacking.

Another important point is that the accidental releases will generally be on a small scale. There have been many estimates of the kinds of radioactive release that go with various kinds of nuclear accidents. The group that made the most definitive study, about eight years ago, was chaired by Professor Rasmussen. Radioactive releases were categorized according to a scale of probability versus release size. On that scale there were some accidents which could result in prompt fatalities, but most fatalities occurred much later.

I would like to remind you, although genuine experts will discuss this later, that the unit of radiation exposure is the rem. Generally speaking, one does not suffer immediate effects below an exposure of perhaps 50 to 100 rem. Over 50 to 100 rem there are visible effects. Over about 400 or 500 rem half the exposed people will die. Those are the prompt effects.

But even "prompt" in those cases does not mean that people fall over like flies in the streets; they do not even die within weeks or months. Later, expert physicians will speak. At least one will tell you that he can save people who have had exposures of 1,000 or 2,000 rem, given the right circumstances. Below about 50 rem of whole body irradiation, all the effects are long term.

As we are learning more about what happens in the circumstances that surround a nuclear accident, the estimates of the number of people likely to suffer acute effects are decreasing. The specific reason is that the releases of ^{131}I and ^{137}Cs, which are major contributors to immediate fatalities, are decreasing in our estimates. People are beginning to understand that in the event of a nuclear accident the atmosphere inside the containment will be a reducing atmosphere, largely because a lot of oxygen in water has been used to oxidize the zirconium that clads the fuel rods. In that reducing atmosphere there will be a great deal of binding of cesium and iodine to each other in the form of cesium iodide. Current estimates are that releases of these two critical materials will be substantially lower than were estimated eight years ago.

In fact, it is entirely within the realm of possibility that as this knowledge develops over the next year or so it will turn out that the best estimate will be that, even in really unimaginably bad nuclear accidents, there will be no immediate fatalities at all. One will deal entirely with long term effects of radiation.

One acute effect is very important: psychiatric care is the care that the population will require as an acute measure. The actual damage to the population—and this was epitomized perfectly well at Three Mile Island—will be completely negligible compared to the panic. Psychological problems are just as real as physical problems. Handling of those problems will be very much an issue confronting the physician population of the area in which the accident occurs. And they can only be handled by those who know something about the subject; bland reassurances will not do.

Beyond this, genuine effects will be latent, and latent effects are subject to some change as time goes by. The last BEIR III report (a report of The Committee on the Biological Effects of Ionizing Radiation) reduced the estimates of the carcinogenic effects of ionizing radiation. (The mutagenic effects are much lower.)

I recall that the number just quoted for Three Mile Island for the total population exposure was approximately 2,000 man-rem. I would have said 4,000, but perhaps that was only man-rem, and when you add the

2,000 women-rem it becomes 4,000. Nonetheless, the average exposure to an exposed individual was something of the order of a millirem.

We will *never* know by epidemiological techniques what a millirem of radiation does to a single individual person. It is easy to do a calculation for a population if I were to take the population of the United States and give it a one-shot exposure of a millirem per person.

Very roughly, that would cause one additional fatal cancer per year in the United States; according to the best estimates probably a little bit less than that. But about 400,000 people die in the United States of cancer every year anyway. And if I have done my statistics correctly, that means we shall have to wait 400,000 squared, which is approximately 100 billion years, to get epidemiological evidence about whether that one millirem did anything to the population. Even that would not work unless our society remained exactly the same for 100 billion years. The only way to learn whether these extremely low doses of radiation do anything to the population is through a better understanding of the mechanisms of carcinogenesis by ionizing radiation.

In any case, the effects will be in this very, very low domain. The consequence of a major nuclear accident, a really major one, will be that people will go around just as they are now, but many of them may have had small doses of radiation, which will have to be understood.

There is one emergency response and public health issue which I wish to mention. I have a simple view of emergency response; the only important thing is that there should be somebody in charge, and that everyone should know who that individual is. If there is anything to be done for emergency planning for accidents around nuclear power plants, it is to make sure that everybody knows who is in charge. The armed services learned that long ago. It does not matter so much who it is, so long as the number of stars is correct and people are able to count up to four. A clear line of authority plus communications are what matter. They are much more important than details of evacuation and sheltering plans that people have. I do not believe in evacuation—I believe in sheltering.

What should be done if there is a major release of radioactivity and people are contaminated? In the event that people do find themselves in a radioactive cloud, there is an urgent need to get them cleaned up before they get too much radiation. If there is an exposure, it will be an exposure in which there will be no immediate visible effects. The important thing will be to get people cleaned off without panicking them. The important thing will be to handle panic. I made an innovative contribution to emergency planning in California last year, of which I am inordinately proud. The emergency plan for a certain county in the event of an accident at a nuclear plant includes the provision that if there is radioactive aerosol in the area, the radio and television programs will be interrupted, telling people to go home, take off all their clothes, take a shower, and put on clean clothes. I suggested that they step into the nearest house rather than go home.

That might help with the psychological aspects of the accident as well. I am rather proud of that suggestion, but I have not checked to see whether it is now part of the emergency plan.

In any case, there will be the problem of cleaning people up, otherwise reassuring them, and trying to estimate how much exposure they have actually had. There will then be the long term problem of watching more carefully those who have had fairly large exposure. In no case, however, will anybody have an exposure to radiation which will increase his chance of dying of cancer by a measurable amount. That is a most remarkable fact. For example, an exposure of 10 rem increases the chance of dying of cancer, according to the best esimates, by less than one tenth of a percent. Since 15% of us die of cancer anyway, that increase will have a very small effect on a very large number of people, probably not measurable, for which no medical attention will do any good anyway except to reduce further exposure.